Extremely Lightweight Fuel Cell Based Power Supply System for Commercial Aircrafts

PI: Chuni Ghosh, PhD, Lead Org: Fuceltech Inc; Subcontractor: Precision Combustion Inc

Project Vision: Develop a new approach fuel cell which is lightweight, small volume, low cost and easier to stack for very high power

Title: Lightweight, small volume fuel cell for efficient stacking for very high power aircraft applications

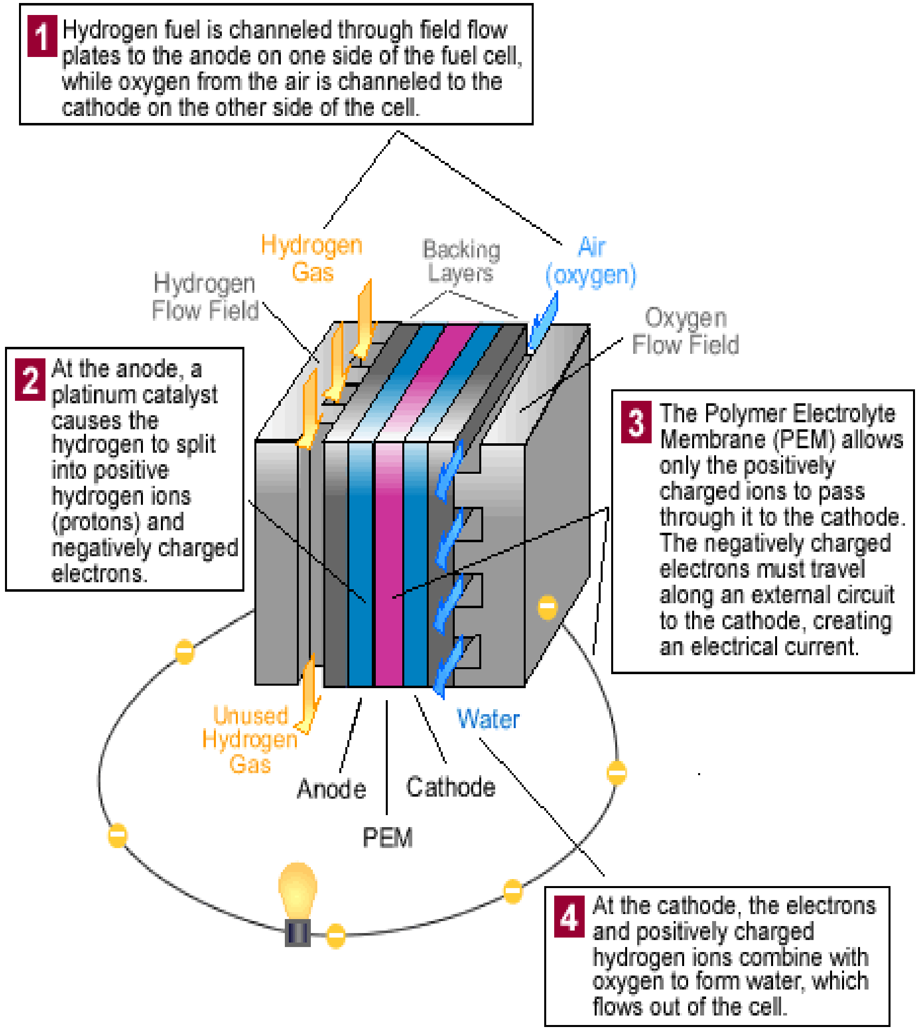
REEACH / ASCEND
Kickoff Meeting
January 26, 27, 28, 2021

Brief REEACH Phase 1 Project Overview

Fed. funding:	$1.6M
Length	24mo.

Context/history of the project:

Developing a new, lightweight, low cost PEM fuel cell



Our first version PEM fuel cell (250W) with the new approach

- The conventional PEM fuel cell is a 50+ year old approach- has hardly changed over time- ours is a radically new approach to reduce weight and volume of the PEM cells
- Conventional approach has heavy graphite bipolar plates- our approach completely eliminates the bipolar plates
- Our first version of the fuel cell was cylindrical (as seen above), but the new versions will be flat and cylindrical- flat version would be easily stackable
- Single cells of 5 to 10kW and stacks with hundreds of kW of power output achievable with our approach

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Team

Team member	Location	Role in project
Fuceltech Inc (Prime)	Princeton, NJ	Will be the primary developer of fuel cell and the stack
Precision Combustion Inc	North Haven, CT	Would develop the reformer using ethanol as the fuel

Context of how the team came together:

- Fuceltech (FTI) is the developer of the fuel cell and stacks- and was looking for a reformer company to work with and Precision Combustion was highly recommended by industry colleagues as the leading technology developer on reformers
- Precision Combustion Inc (PCI) will develop the reformer for alcohol to convert it into the high purity fuel for the PEM fuel cells and stacks
- Fuceltech is a new company in the fuel cell space, but the Principal Investigator has worked on ARPA-E programs in the past. Precision Combustion has worked on ARPA-E programs in the past

Company Backgrounds

Fuceltech Inc (FTI):

- Located in Princeton, NJ, Fuceltech is a new entrant in the fuel cell field
- Started by a founder with deep experience in major technology development and commercialization of technologies developed from government contracts
- They have a radically new approach for high power, lightweight and low cost fuel cells
- Developing the technology and want to move rapidly towards commercialization

Precision Combustion Inc (PCI):

- Located in North Haven, CT, is a developer of reformer systems and has developed significant technologies for new generations of reformers with different fuels for fuel cell systems
- Has developed technologies which can be used for alcohol reforming for PEM fuel cells delivering high purity feed gas for PEM fuel cells
- Would commercialize the technologies developed out of the ARPA-E program

Key Team Members (continued)

Dr. Chuni Ghosh, PI and Chief Engineer, FTI

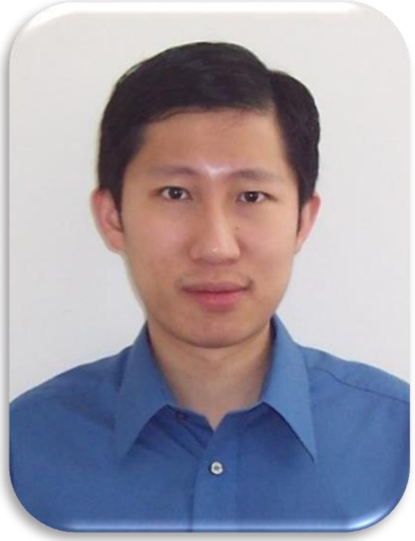
Dr. Ashish Chouhan, Senior Engineer, and key researcher, FTI

Dr. Qing Wang, Senior Principal Engineer, and key researcher on design and construction, FTI

Prof. Ajay Prasad, Consultant with the fuel cell and stack approach, FTI

Dr. Hani A.E. Hawa
Research Engineer, PCI

H_2 Production, Gas Separation Membranes, Additive Manufacturing



Dr. Christian Junaedi
Senior Program Manager and Principal Scientist, PCI

Fuel Reforming, SOFCs, Reactor Design, Catalysts, Sorbents

Innovation

- *Novel aspects of the technology:*

For the ESPG System we would use:

- *A new approach of PEM fuel cells which will be 3x lighter weight and 2x lower volume compared to the current state of the art and which would deliver very high power of multiple kW from a single cell (2kW in phase 1, 5kW in phase 2)*
- *The PEM fuel cell is highly stackable for very high output power of several hundreds of kWs to MWs of power output from single or multiple stacks*
- *A new type of reformer by PCI to convert alcohol to the reformates with much lower carbon monoxide contamination issues which can be used as fuel for PEM fuel cell*

For the fuel cells the novel aspects of the technology are the following:

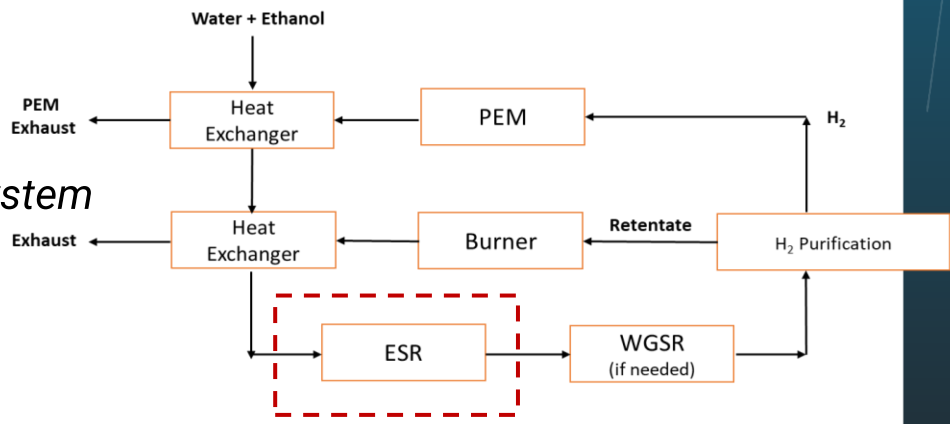
- *PEM fuel cell construction has not changed in over fifty years. They are bulky and heavy because of bipolar construction needing heavy graphite plates which are 80% of the weight and 50% of the volume*
- *Our approach is a new unipolar construction compared to the bipolar design of the current state of the art- the bipolar plates are heavy and expensive. Our proposed technology would lend to much lighter weight construction*
- *Unipolar proposed construction is lower in volume more than 2x lower volume and 3x lower weight vs current state of the art approach of PEM fuel cells*
- *It's much easier to stack the cells for higher power without adding to water condensation problem that is encountered in conventional PEM fuel cells.*

Key Objectives for the PEM Fuel Cell for REEACH

- *Development of a 5kW single fuel cell and a 10kW stacked output power fuel cell*
  - *Year 1-2 (phase 1): 2.0 kW single fuel cell and 5kW stack design*
  - *Year 1 target 500W from a single fuel cell with a power density of 1W/cm2 @0.75V*
    - *Degradation rate of <1% per 1000 h at rated power in steady operation over 250hr test*
  - *Year 2 target 2kW single fuel cell and 5kW stack design*
    - *Specific power of at least 2.5kW/kG when operating at 0.75V with <1% degradation per 1000hrs*
  - *Year 3-4 (phase 2): 5 kW single fuel cell and 10kW stack build*
    - *Single cell of 5kW power operating from reformates from the reformer system*
    - *10kW fuel cell stack demonstration*

Objectives: PCI's ESR Technology & Key Metrics for REEACH

- *Development of a 5 kW_e Ethanol Steam Reformer (ESR) system for integration with FTI's PEM fuel cell system for aircraft implementation*
  - *Year 1-2 (phase 1): 1.0 kW_{th} sub-scale ESR demonstration (without H_2 purification component)*
    - *Target reforming efficiency: >80% (LHV-based)*
    - *Target energy use: <42 kWh_{th}/kg H_2 (LHV-based)*
  - *Year 3-4(phase 2): 5 kW_e system integration with suitable H_2 purification system*

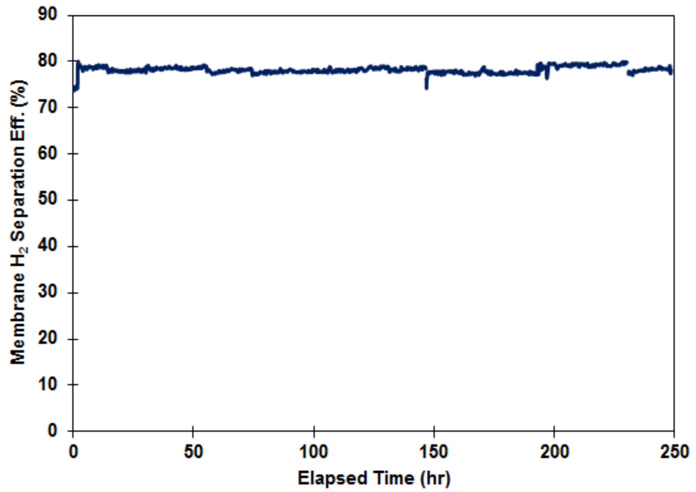


Focus of Year 1-2

- *Complete a detailed design for a 5 kW_e Ethanol Steam Reformer (ESR)*
  - *5 kW_e ESR prototype will be built in Year 3-4*
- *Perform process simulation using commercial simulation software*
  - *Identify operating parameters for optimum efficiency*
- *Fabricate & demonstrate sub-scale (~1 kW_{th}) reformer performance under representative operating conditions*
  - *Provide the composition of the reformate gases to Fuceltech, Inc. for their stack testing*
  - *Use sub-scale results to finalize the design for the 5 kW_e ESR*
- *Evaluate technology availability/readiness, manufacturability, and cost*

Objectives: PCI Reforming + H_2 Purification System

- ***PCI has demonstrated a 6 kW_{th} steam reformer using Sasol IPK GTL fuel (syn-diesel)***
- ***Separation of H_2 can be accomplished via PSA or membrane***
- ***Demonstrated stable system operation (Steam reformer + water gas shift reactor (WGSR) + membrane)***
  - ***99.95% H_2 purity & ~77% separation efficiency***
  - ***~2.2 kg/day of H_2 was produced at 11 atm***
  - ***PCI has also developed WGSR and PROX reactor of CO to produce PEM-quality H_2 with <10 ppm CO***



H_2 separation efficiency achieved during the integrated H_2 generator testing over ~250 hours. The steam reformer was operated with GTL fuel (Sasol IPK.)

Performance of Microlith Based Catalytic Reactors for an Isooctane Reforming System; SAE International; 2003-01-1366

Risks and Challenges (Fuel Cell)

Technical Risks	Technical Risk Category	Mitigation Approach
• (1) Pressure drop at high power too high	• Minor	• Flow rate and pressure have to be optimized as we move from lower to higher power, through simulations and experiments and modifying cell design
• (2) Unacceptable temperature rise at the center of the fuel cell	• Moderate	• The temperature rise at the center should not exceed 90 deg C to maintain efficiency and performance. Through simulations and experiments where we measure temperature by thermocouple, we would be able to determine various parameters to maintain temperature rise to an acceptable level
• (3) Stack related risks: High and uneven stack temperature at high power damages the MEA	• Moderate	• For high power operation the stack temperature should be maintained at steady level for efficient heat exchanger operation. That temperature has to be determined and the power level has to be optimized for operation at that temperature operation
• (4) Technology adoption risks	• Minor	• Demonstrating FC and ESR performance and durability • Performing T2M tasks will enhance technology adoption by the market

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Risks and Challenges (ESR System)

Technical Risks	Technical Risk Category	Mitigation Approach
• (5) H_2 separator/purifier weight too high	• Moderate	• Select separator/operating conditions to maximize efficiency for reduced footprint and weight
• (6) Meeting PEM quality H_2 purity and flow rates	• Minor	• Optimize separator based on tradeoff between system weight, purity, and life
• (7) Reformer system efficiency below target	• Moderate	• Thermodynamic analysis to inform optimal operating conditions and achievable efficiencies • Utilize subscale testing and validation
• (8) Obtaining a thermally-balanced system	• Moderate	• PCI has experimentally validated steam reforming with several approaches to tune the heat balance • Process simulation software will be used to validate a thermally-balanced system configuration
• (9) Methane formation (reducing efficiency) • (10) Catalyst coking (reducing lifetime)	• Minor	• Use process model to optimize S/C ratios, temperature, and pressure to avoid coke and methane formation • Use subscale data to confirm operating conditions
• (11) Retaining water neutral operation	• Moderate	• Identify suitable configuration via process model & test data
• (12) Technology adoption risks	• Minor	• Demonstrating ESR performance and durability • Performing T2M tasks will enhance technology adoption by the market

Risk Assessment Chart

Technical Risks	Technical Risk Category
(1) Pressure drop at high power too high	Minor
(2) Unacceptable temperature rise at the center of the fuel cell	Moderate
(3) Stack related risks: High and uneven stack temperature at high power damages the MEA	Moderate
(4) Technology adoption risks	Minor
(5) H_2 separator/purifier weight too high	Moderate
(6) Meeting PEM quality H_2 purity and flow rates	Minor
(7) Reformer system efficiency below target	Moderate
(8) Obtaining a thermally-balanced system	Moderate
(9) Methane formation (reducing efficiency) (10) Catalyst coking (reducing lifetime)	Minor
(11) Retaining water neutral operation	Moderate
(12) Technology adoption risks	Minor

Likelihood	Insignificant	Minor	Moderate	Major	Catastrophic
Almost Certain					
Likely					
Moderate		1,4, 6, 9, 10, 12	2, 3, 5, 7, 8, 11		
Unlikely					
Rare					
	Consequences				

Task Outlines for Fuel Cell and Reformer System

WBS	Task or Milestone Title	Task or Milestone Descriptions	Start qtr	End qtr	Q1	2	3	4	5	6	7	Q8
M2	**Fuel cell related tasks**											
M2.1	Thermal Simulation	Do simulation for the fuel cellfor power and cooling need	1	2								
M2.5	Build and tes 500W performance cell	A 500W fuel cell will be built	3	4								
M2.7	**Go/NoGo 500W Fuel cell meet specs**			4								
M2.8	Meet 500W cell all specs	The 500W fuel cell will be thoroughly tested.	5	6								
M2.9	Fuel cell build 2kW and test	2kW fuel cell will be built with this technology	4	6								
M2.11	**Go/NoGo 2kW fuel cell**			8								
	Reformer related tasks											
M3.3	Design of the subscale ESR including purificatin tech	The subscale ESR will be designed and simulated for performance	3	4								
M3.4	Fabrication and testing of the subscale ESR	The subscale ESR will be built and tested	4	8								
M3.7	**Go/NoGo ESR design and Demo**		7	8								
M4	**Systems Design**											
M4.1	Complete design of 5kW FC, ESR and H2 purify system and 5kWe	The complete ESR for 5kWe output will be designed for building in phase 2.	4	8								

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Technology-to-Market Approach

- *Our technology will make the PEM fuel cells 3x lighter, 2x smaller in volume, 10x cheaper compared to existing technology. Our high volume cost target is <$15/kW compared to current market price of >$150/kW. These are the key differentiators*
- *The fuel cell market is growing at a CAGR of >20%, supposed to be about $25B by 2024, according to some market studies.*
- *Our Goal: Manufacture the products in our company and sell them directly from the company or through distributors. Start commercialization 2023-24 time frame with venture capital financing.*
- *The markets are for stationary power source, automotive, drones, remote power applications and commercial and military aircraft markets. Our differentiators are lower cost, lighter weight and smaller volume. This is a winning combination for the markets we are targeting.*
- *The first targeted market will be stationary power market for warehouses, office complexes and remote power applications. These applications are very cost sensitive and our products will have strong customer appeal because of our low cost.*

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